Rocky Mountains
Southwest
Great Plains

Research Note RM-425

March 1983

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station

The Deadhorse Experiment: A Field Verification of the Subalpine Water Balance Model

Charles A. Troendle[1]

Thirty-six percent of a small, 41-ha, subalpine watershed on the Fraser Experimental Forest was harvested using a system of small 5-H circular clearcuts. Simulations, using the Subalpine Water Balance Model, indicated that a 4.3-cm increase in flow could be expected in an average year following the proposed treatment. Predictive techniques also indicated 30% more snow would be deposited in the openings. Annual water yield has increased an average of 4.6 cm during the first 4 years after treatment with no detectable effect on peak flow rates. Significantly more snow was found in the openings than in the forest, but mean peak water equivalent for the watershed was not significantly altered.

Keywords: Watershed management, water yield, snow hydrology, clearcutting, modelling

Introduction

Timber harvesting reduces evapotranspirational demand, alters the soil moisture regime, and results in increased streamflow. Hibbert (1967) first summarized the effects of 39 worldwide watershed experiments, which addressed vegetation/streamflow relationships. More recently, Bosch and Hewlett (1982) summarized the effect of 94 catchment experiments worldwide. Within the subalpine forests of the Rocky Mountain Region, three watershed experiments have determined the effect of timber harvest on water yield. The Wagon Wheel Gap Watershed was the first paired watershed experiment in the region and in the United States (Bates and Henry 1928). The 81-ha aspen and conifer watershed was clearcut in 1921. The increase in flow, which was as much as 5-cm, was diminished to pretreatment levels in only 5 years because of the rapid regrowth of aspen. Fool Creek, a 289-ha watershed on the Fraser Experimental Forest was strip-cut in 1955 (Goodell 1959). The first-year average increase in flow following the clearcutting of 40% of the watershed was 8.9 cm. Twenty-five years later, regrowth of the lodgepole pine and spruce-fir had only reduced the initial effect by one-third (Troendle and Leaf 1981). In a third, but less rigorous, watershed experiment, Swanson and Hillman (1977) reported on a series of watersheds on the James River in Alberta that were harvested to differing degrees of intensity. Although a paired watershed approach was not used, comparison of cut and uncut watershed responses indicated an effect of treatment very similar to that for Wagon Wheel Gap and Fool Creek.

The Fool Creek Watershed Experiment and the associated supporting research in the nearby subalpine forests have led to accumulation of a large body of knowledge concerning the effect of timber harvest on snowpack accumulation and melt as well as its effects on streamflow (Leaf 1975).

As a result of these watershed experiments and also the comprehensive snow accumulation and melt studies in the same and similar areas, techniques or models have been developed to allow prediction of management alternatives on the water resource. An example is the Subalpine Water Balance Model (Leaf and Brink 1972a, 1972b).

The Deadhorse Creek watersheds, on the Fraser Experimental Forest, are being used as pilot demonstration areas to which optimal watershed, timber, and wildlife strategies can be implemented, responses predicted, and simulations evaluated. This paper examines the water yield improvement treatment applied to the North Fork drainage.

[1]The author is Research Hydrologist at the Rocky Mountain Forest and Range Experiment Station's headquarters in Fort Collins, in cooperation with Colorado State University.

Watershed Description

Deadhorse Creek is a 270-ha watershed on the Fraser Experimental Forest, Colorado (fig. 1). It drains to the east at elevations ranging from 2880 m to 3536 m. Two subdrainages of Deadhorse Creek are the 41-ha North Fork, and the 78-ha Upper Basin. Adjacent to the Deadhorse Creek is Lexen Creek, the 124-ha control watershed for all three drainages in the Deadhorse Creek complex. Because the average elevation of Lexen Creek is higher than Deadhorse, its slightly greater snow pack melts later than Deadhorse, and the resulting streamflow is greater.

Soils in both the Deadhorse and Lexen Creek drainages consist of alluvium and glacial outwash in the lower portions of the steep-sided valleys. The upper slope positions and all high elevation sites are partially occupied by sedimentaries, remnants of the Dakota and Morrison sandstone formations (Retzer 1962). The parent material for most of the soils on the side slopes and below the sedimentaries was derived from gneiss and schist and has formed deep, gravelly soils with low erodibility. As a result there is little or no surface erosion. The soils are capable of absorbing water at rates far in excess of snowmelt and rainfall intensities which have occurred during the period of record.

Snowpack accumulation and melt over and between the drainages is quite variable (Leaf 1969). The combination of steep side slopes that average 40%, opposing north and south aspects, and the wide range in elevations (600+ m) all cause the energy load to vary greatly. As a result, the snowpack on the North Fork of Deadhorse Creek (mostly mid-elevation, south facing) is melted well in advance of that for either the higher elevation Upper Basin of Deadhorse or the Lexen Creek watersheds (Leaf 1969). The resulting flow from the North Fork peaks sooner and recedes faster than Lexen Creek (fig. 2).

Forest cover on the watersheds consists of spruce-fir stands along the stream channels, on north slopes, and

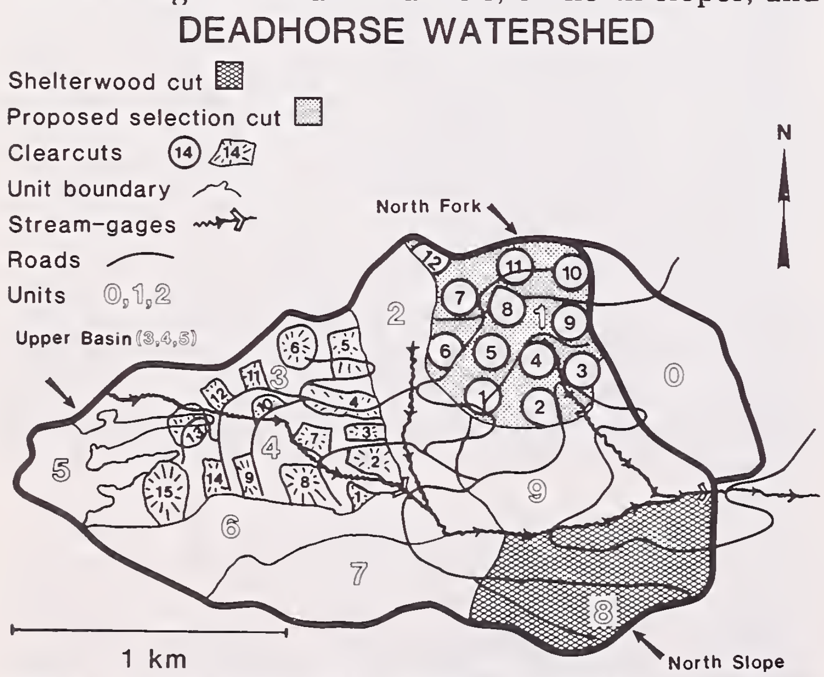

Figure 1.—The Deadhorse Watershed complex showing proposed management alternatives for the North Fork, Upper Basin, and North Slope units.

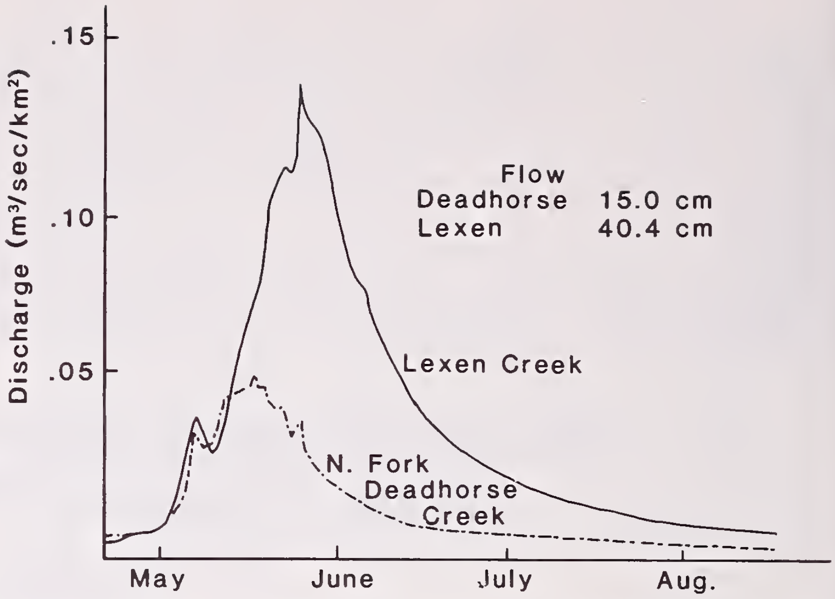

Figure 2.—Comparative hydrographs from North Fork and Lexen Creeks for an average water year prior to harvest on North Fork.

at upper slope positions. Lodgepole pine grows on all low and mid-elevation southerly or high energy exposures. Alpine tundra is above timberline. There is an average of 168 $m^3 \cdot ha^{-1}$ of sawtimber on the forested portion of the watershed. The North Fork watershed, because of its mid-elevation southerly exposure, consists mostly of the lodgepole pine. A portion (7 ha) of the North Fork watershed was cut-over more than 40 years ago, but the regrowth, although not merchantable sawtimber, completely occupies the site hydrologically.

Treatment and Measurement Methods

The 120° V-notch weirs on Main Deadhorse and Lexen Creeks were built in 1955. The weir on the North Fork of Deadhorse was built in 1970; the streamgage on the Upper Basin of Deadhorse Creek was constructed in 1975. All weirs have been operated from April to October of each year since construction.

In addition to obtaining long-term streamflow records; snow courses, to index peak water equivalent; precipitation; temperature and humidity; and annual sediment export have been continually monitored. Comparative snow course observations between the Deadhorse Creek and Lexen Creek were begun in spring 1967 and are used to estimate the mean water equivalent for each of the subdrainages. Samples are collected at 40-m intervals along transects that cross all major slope aspects and elevations. The estimate of mean water equivalent is used to index winter precipitation. Five rain gages (two recording and three standard) on Deadhorse and one standard gage on Lexen Creek are used to index the precipitation. Temperature and humidity are measured on two sites, one north-facing and one south-facing slope, on Deadhorse Creek.

In addition, each fall, a grid of closely spaced cross sections is used to define the surface elevation of the sediments in the weir pond. The pond is then cleaned, and the new surface is defined. The difference between the two surface levels is considered to be an estimate of the volume of organic/inorganic material exported from

the drainage. Using predetermined relationships this total volume is converted to volume and weight of inorganic material (Leaf 1974).

In 1970-71, a 2-mile extension of the main access road was constructed through the main Deadhorse Watershed to gain access to the gaging sites on the North Fork and Upper Basin. In 1977, 0.5 km of main access road and 4.0 km of spur road were constructed in the North Fork watershed to facilitate the patch clearcutting. The road network consists of a narrow 3-to 4-m roadbed, built as much on contour as possible to minimize grade, and drained primarily with rolling dips. It was built to be permanent, be used for future entries, and require minimal maintenance. In total, about 2 ha of surface were severely disturbed (log decks, roads, etc.) by the harvesting operation.

Subsequently, 36% of the forest was removed by clearcutting 12 small units, uniformly spaced through the drainage. The circular openings are about 122 m or 5-H in diameter and occupy about 1.2 ha each. Timber on 11 of the openings was harvested in 1977, and the remaining opening was cut early in the summer of 1978. Harvesting consisted of felling all trees 10 cm in diameter and larger and removing all merchantable material from the site. All slash was lopped to a 10-cm top and scattered. Approximately 2450 m³ of sawtimber was harvested from the North Fork watershed.

Since that time, the road system has been used intermittently during ongoing research and, except for a "surface grading" after the logging operation, no mitigative practices have been used other than the "best management practices" used in initial design and construction.

Response to Treatment

Effect on Snowpack Accumulation

Figure 3 demonstrates the pretreatment and posttreatment relationship of the peak water equivalent index for the control and treated watersheds. Based on covariance analysis, the observed relationships have not changed as a result of treatment. R^2 for the pretreatment relationship was 0.94, and it was 0.97 for the 4 years since harvest. There was no detectable change in average water equivalent (measured about April 1 each year) on the watershed as a result of the treatment. It is assumed that the net precipitation input has not changed as a result of timber harvest. Its placement, stability, and melt characteristics have been altered but not the total amount.

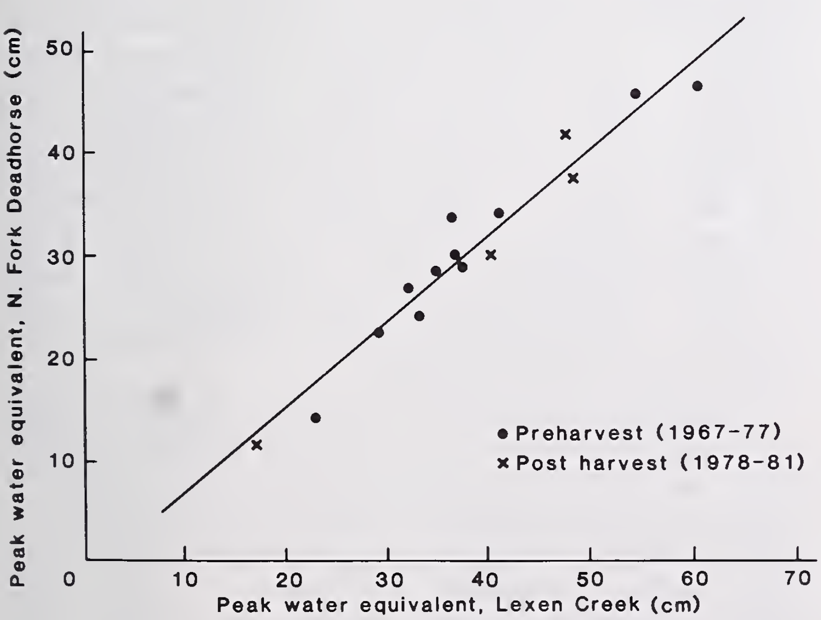

Figure 3.—The relationship of peak water equivalent on the North Fork of Deadhorse with that for the control, Lexen Creek.

In addition to the snow course observations, several of the openings, as well as the forest around them, have been sampled intensively. Snow tube samples were taken at 12-m intervals along transects that started in the forest, passed through the center of the openings, and continued into the forest to the next opening. In most cases, two transects per opening were made—one parallel to the prevailing winds, the other perpendicular to them. The mean water content for the samples taken in the forest was 40 cm, while it averaged 52 cm for those taken in the openings. Because the overall watershed mean, as indexed by the snow course, did not change, it can be assumed that a change occurred and that the increase in snowpack in the openings is a reflection of the change in depositional and redistribution patterns caused by the harvest. The water equivalents for the forest and the open samples were then area weighted and averaged to obtain the mean represented by the transect samples. The weighted mean was 44.2 cm. The average 52 cm of water observed in the openings reflects an 18% increase relative to the mean for all subsamples and is compensated for by a reduction in the surrounding forest. The 18% increase is somewhat less than the 30% increase predicted for the 5-H openings using the Rho function developed by Troendle and Leaf (1980). However, of the 12 openings, 6 are spaced less than 3 H (at the closest point) from the next downwind opening, and the spacing between openings should be at least 5 H to be optimal. Because of the less than optimal spacing and the reduced redistribution efficiency, the observed 18% increase in accumulation in the openings is reasonable. The greater amount of water equivalent in the openings is also generally consistent with other observations made by Gary (1981), Golding (1981), Troendle and Leaf (1981), Leaf and Alexander (1975), and others.

Effects on Water Yield

Streamflow from the North Fork of Deadhorse was calibrated against that from Lexen Creek for a 7-year period (1971-77) before harvest. The least squares fit on total yield had an R^2 of 0.98 with a standard error of 1 cm. Table 1 presents observed flow from North Fork watershed and the change in flow attributed to treatment. Also presented is the precipitation for the 4 years involved. The latter is significant because the magnitude of the increase in flow strongly depends on annual precipitation. The wetter years produced the largest increases in flow (fig. 4). Covariance analysis indicated

Table 1.—The observed increase in flow following timber harvest on the North Fork of Deadhorse Creek

Year	Precipitation	Total flow	Increase
	<-------------------	cm -------------------	>
1978	62.7	23.1	3.6[1]
1979	70.9	21.1	5.8
1980	71.9	23.1	6.6
1981	51.8	9.4	2.0
$\bar{x}$	64.8	19.3	4.6

[1]*During harvest*

that the 36% increase in flow observed during the 4 posttreatment years is significant at the $P = 0.05$ level and appears to be linear with volume of flow.

Figure 5 is a plotting of an annual hydrograph for Lexen and North Fork for water year 1980. Flow from Lexen Creek is comparable to that for the hydrograph shown in figure 2. The observed increase in flow appears on the rising side of the hydrograph and results from a combination of advancing the spring melt by exposing the pack to sunlight and the reduction of soil water deficits from the previous growing season. The increase in flow for 1980 was 6.6 cm; figure 5 presents a reasonable characterization of when and where the increase occurred.

The monthly flows for May to August were also calibrated for North Fork and Lexen Creeks, and individual confidence limits were placed on each of the monthly flows for the 4 posttreatment years to evaluate impact. May was the only month where flow differences were significant ($P = 0.05$). Total flow for May in both 1978 and 1980 was significantly increased; 1979 was of borderline significance. The analysis indicates that the total flow for May of 1980 was increased by 4.1 cm and represents more than half of the annual change. This is the largest single month increase in the 4 year post-harvest record. No flows for months other than May

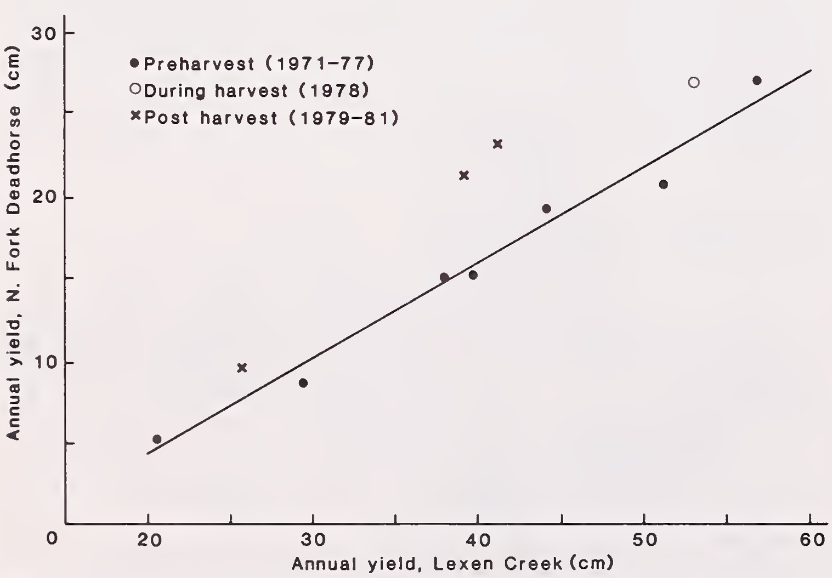

Figure 4.—The relationship of annual yield from North Fork of Deadhorse and from Lexen Creek, the control, during the calibration period and for the four posttreatment years.

were significantly affected. Subsequently, a covariance analysis was performed on the pretreatment and posttreatment streamflow data for the month of May. The multivariate analysis indicated that the adjusted mean flow for the month of May on Deadhorse Creek was 4.2 cm before harvest and 7.6 cm after harvest. The average 4-year increase of 3.4 cm is significant at the $P = 0.05$ level. The record is too short to support a more thorough flow interval analysis.

It has been generally noted that 20-30% of the watershed has to be harvested before a significant change in flow can be detected (Troendle and Leaf 1980). In the case of the North Fork, 36% was harvested, and a significant change in flow was detected. However, the area harvested, on the North Fork, represents only 5% of the drainage gaged by the main weir downstream. The calibration relationship for the main weir and Lexen Creek is much longer, 1956-77, and has an R^2 of 0.98. Figure 6 represents a plotting of the calibration relationship that existed between main Deadhorse and Lexen Creek along with the four posttreatment observations. The treatment on the North Fork of Deadhorse has had no detectable effect downstream, at least as indexed by the main gage. This is a significant observation because the effect is established "onsite" and the increase is in the system, but the ability to detect it downstream is difficult because the increase is only part of the "noise." The main stream in Deadhorse is a second-order perennial channel, and there is no reason to believe the increase from the North Fork could be eroded or dissipated away in transit. The magnitude of change would not cause a significant increase in either the wetted or evaporative surface along the channel, seepage to groundwater, or an increase in consumptive use by vegetation. It is assumed that the increase has not been "lost" but is simply not detectable at the main gaging station.

Figure 7 represents the pretreatment and posttreatment observations of peak dischrarge of both North Fork and Lexen Creek. Both confidence limits on individual posttreatment observations and covariance analysis indicated that no significant change occurred in the magnitude of the peak discharge of Deadhorse Creek following harvest. The error term on the peak flow relationship based on 4 posttreatment years is large, and a long period of record will be necessary to evaluate what may be a minor, if any, change in peak discharge. Covariance analysis indicated that the time of peak (number of days from May 1 on which the peak occurs) was not significantly ($P = 0.05$) affected by the harvesting. The mean of the average date of peak occurrence was advanced two days.

A more thorough analysis of treatment effect is somewhat restricted because only 4 years of posttreatment record are available. Fortunately, those 4 years cover a range in climatic and flow conditions that equal the range observed during the calibration period. Although this supports the general conclusions on mean peak water equivalence in the snow pack, annual flow changes, and downstream effects, the precision makes detection of what can be no more than small changes in

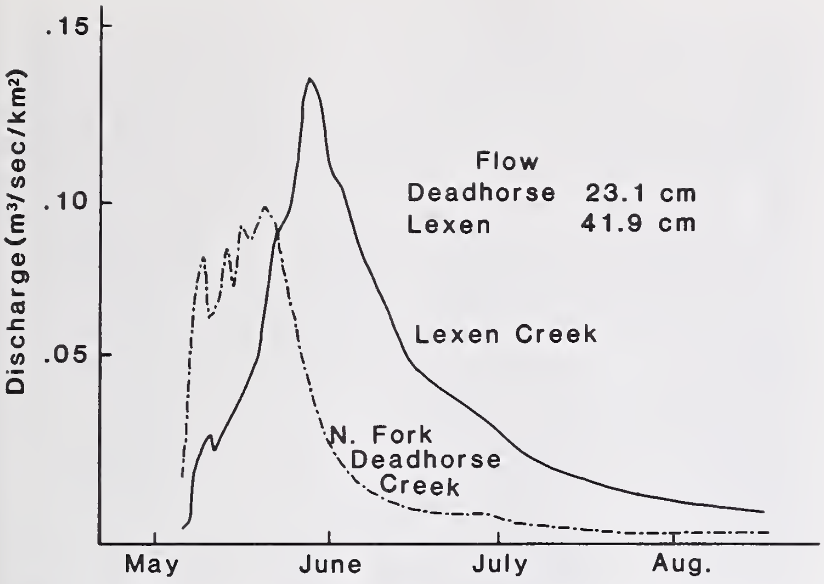

Figure 5.—The relationship between annual yield from Main Deadhorse and Lexen Creeks for pre- and posttreatment conditions.

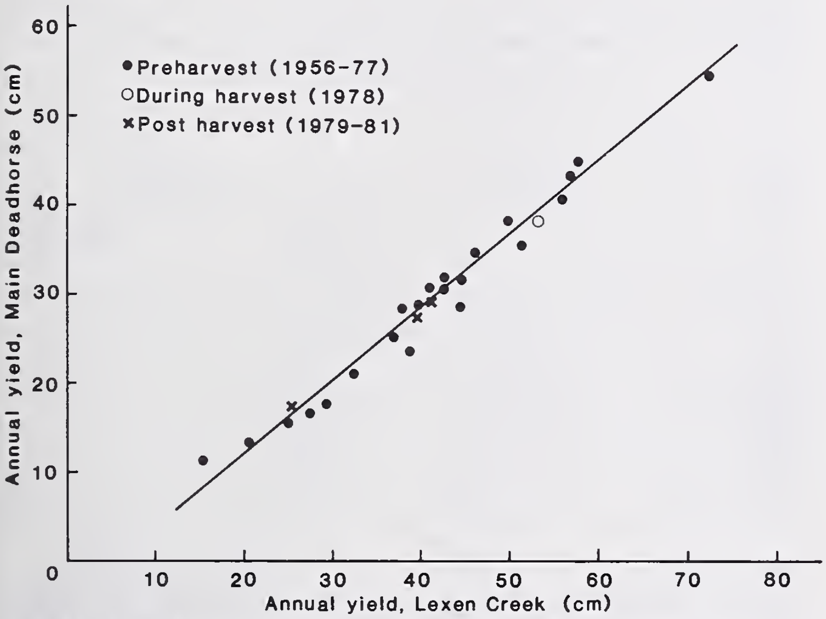

Figure 6.—Comparative hydrographs from the North Fork of Deadhorse and Lexen Creeks for an average water year during the posttreatment period.

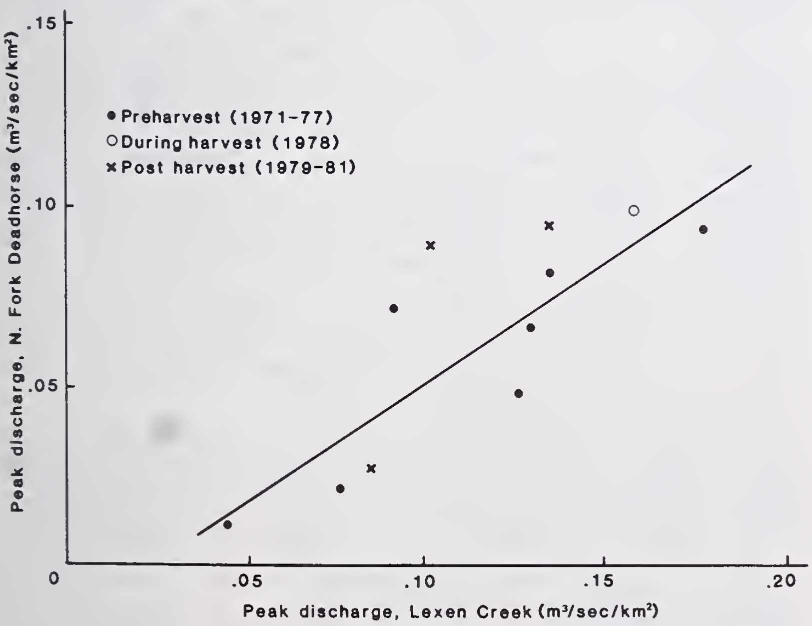

Figure 7.—The relationship between peak discharge from the North Fork of Deadhorse and Lexen Creeks for the pre- and posttreatment periods.

peak flows, timing of peak, duration of various flow levels, and other hydrograph descriptors less conclusive. For a thorough analysis of these descriptors, a longer posttreatment record is needed.

Effect of Treatment on Sediment Production

Water quality observations on Deadhorse and Lexen Creeks have been minimal. Sediment export has been estimated based on the annual accumulations in the weir ponds. Leaf (1974) noted that the efficiency at which sediments settled out and into the ponds was quite high, even at peak flow rates. As a result, the annual accumulation of material in the ponds is a good index to the suspended and bedload export from the drainage.

The 7-year calibration of sediment production from North Fork to Lexen Creek was not particularly strong ($R^2 = 0.75$) but it does allow prediction of expected amounts for North Fork during the posttreatment years based on the export from the control watershed. The road system represents the primary disturbance to the North Fork.

Table 2.—Expected and observed sediment production from North Fork of Deadhorse Creek following timber harvest

Year	Expected sediment	Observed sediment	Increase
	< ----------	kg/ha	---------- >
1978	21.6	58.2	36.6
1979	15.0	29.7	14.7
1980	17.8	25.9	8.1
1981	13.2	2.6	-10.6

Table 2 lists the expected sediment production from the watershed. This is estimated using the calibration period relationship or equation and applying it to the posttreatment sediment production from the control watershed. The observed increase represents an estimate of the combined effect of the road building/harvesting operation on sediment production and is approximated as the difference between expected and observed sediment. The first-year increase of 36.6 $kg \cdot ha^{-1}$ is conservative relative to the increase observed from the Fool Creek experiment (Leaf 1974). However, the road system on Deadhorse is better designed, located, and drained than the system on Fool Creek, and it apparently has had a more minimal impact. The recovery during the 4 postharvest years seems to be quite rapid—as it was on Fool Creek. Longer record is necessary to assure that recovery has actually been achieved.

The activities within the drainage, while causing an effect "on-site" (such as at the North Fork weir), have not translated downstream to the main weir, so that the "offsite" effect of these activities has been minimal, or at least undefinable, to this point. The sediment observations in this experiment, although quite limited, indicate that road construction and timber

harvest had very little effect on sediment production from the treated watershed.

Sediment production following road construction and timber harvest on the nearby Fool Creek watershed has been monitored since 1951 (Leaf 1974, Troendle and Leaf 1981). Figure 8 represents the accumulated sediment production from the Fool Creek watershed from 1955 to 1980 plotted over time. It can be noted that two relationships exist, that for years one through four (1955-1958) and the period since then. In 1957, some of the culverts were pulled on the 12.0 km of spur roads; they were seeded, and then abandoned. The 5.3 km of main haul road that were not abandoned have been in continuous use and have received annual maintenance such as surface grading and ditch and culvert cleaning. In total, 14.1 ha of roads and log decks were originally built with 3.7 ha or 5.3 km of roads still being used. This is in contrast to the Deadhorse road system where the roads are not open to the public and in effect, have been abandoned. It can be noted that the slope of the sediment accumulation from Fool Creek for the years 1959 to present is one-fourth of that for the 1955 to 1958 period. This is the same proportion as that for the area disturbed for the two periods.

Stabilization or recovery of the abandoned portion of the road system on Fool Creek was very rapid as it has been on Deadhorse Creek, and there has been no need for costly mitigative practices or loss of the access system for future entry. However, continued use, such as that on a portion of the Fool Creek roads, appears to have a lasting and constant effect on sediment production.

Water Yield Prediction

One of the objectives of the Deadhorse pilot study was to evaluate and verify the capability to simulate in advance the effect of the management alternatives applied to the various subdrainages of the Deadhorse watershed. Leaf (1975) simulated the expected hydrologic response of patch clearcutting on the North Fork watershed using the Subalpine Water Balance Model (Leaf and Brink 1972). The simulation represented the average response that could be expected for the first 10 years following treatment, given a normal climatic regime. Although the model is quite sophisticated in both data requirements and execution, the simulations were geared to management application needs and, therefore, were presented as average expected response. Leaf's average simulation is presented in table 3. Because the average of the climatic conditions for the 4 posttreatment years approach the long-term mean for the watershed and the conditions under which the simulation is intended, the comparison of the mean of the observed changes and the mean simulated change is quite good.

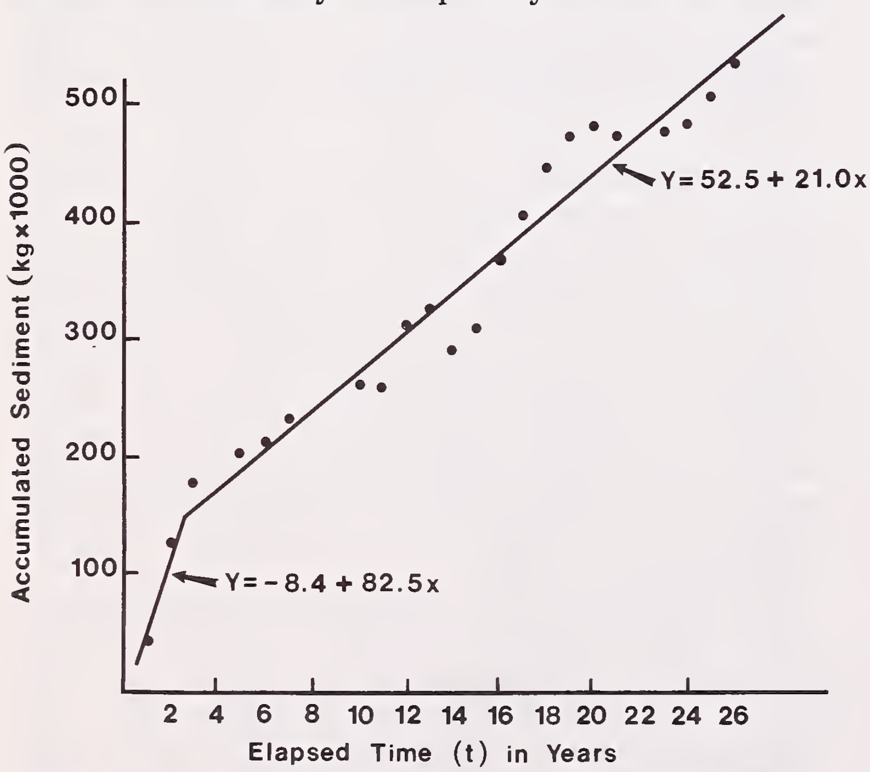

Figure 8.—The accumulated sediment production from the Fool Creek Watershed for the period from 1955 to 1980.

Table 3.—The comparison of observed changes in flow from the North Fork of Deadhorse Creek with those simulated using the Leaf-Brink and WRENSS models

Year	Observed increase	Simulated increase	
		Leaf	WRENSS
	<----	cm	---->
1978	3.6	3.8	2.3
1979	5.8	4.6	4.6
1980	6.6	4.6	5.0
1981	2.0	4.6	4.1
$\bar{x}$	4.6	4.3	4.1

The WRENSS hydrology model (Troendle and Leaf 1980) is a simplified nomographic procedure for predicting hydrologic impact. Developed in part from experimental observations and the application of models, WRENSS is far less data-demanding than the parent procedures from which it was developed (the Subalpine Water Balance Model was used to develop procedures for the Rocky Mountain Region). The WRENSS simulations are also presented in table 3. They were made using the same data set that Leaf (1975) used, except that observed annual precipitation was used to drive the WRENSS model because the WRENSS procedure was applied "after the fact." On the average, the WRENSS model also performed quite well, but it is apparent that errors are quite large when site-specific estimates are made on an annual basis.

The subalpine water balance model was developed on the Fraser Experimental Forest. One objective of the Deadhorse experiment was to verify whether the model could predict response, at least under the conditions for which it was developed, realizing that this would not be a good evaluation of its universality. The model functions well at Fraser. More complete testing is needed off the Fraser Experimental Forest and under differing harvesting practices.

Summary and Conclusions

The initial phase of the Deadhorse experiment resulted in a response that is consistent with other observations in the subalpine. As in the Fool Creek experiment, net water equivalent in the snowpack, and precipitation input, did not significantly change. Secondary observations indicate snow was significantly redistributed, with significantly more snow located in the open and less in surrounding forest. The resulting change in flow occurred early in the year, as it did on Fool Creek, but the magnitude of change is smaller relative to the proportion of the watershed area cut. This may partly result from the fact that the clearcuts on Deadhorse are discontinuous and not connected to the stream, allowing some loss of evapotranspirational (ET) savings "en route." The Deadhorse watershed appears to have hydrologically shallow soils and, therefore, would present opportunities for extraction of the savings as the migrating water would more likely pass through a rooting zone downslope. Another factor may be that the redistribution efficiency was reduced because of the less than optimal spacing of the openings.

Two other observations bear this out. In 1977, 11 of the patches were harvested during the summer, with little apparent opportunity to reduce ET. In 1978, there was a significant increase in flow, implying that there had to be some reduction in normal recharge requirements the preceding year. This would be the result of a more dynamic, but minimal, hydrologic depth (or storage capacity on the watershed). The 1980-81 winter was a near record dry year with only 5 cm of water equivalent in the snowpack on March 1, 1981, whereas normally 25 cm would be expected. The spring precipitation was normal, while the summer (July-October) precipitation was above normal. As a result, summer flows were maintained at higher levels, causing a 2-cm annual increase. Because 1981 was the only year not to have a near-significant increase in May, the increase must have been distributed through the entire season. This also probably reflects the more dynamic ability of Deadhorse to respond to precipitation, whenever it occurs, than Fool Creek demonstrated.

Although the overall response is somewhat similar to that from Fool Creek, extended records will be useful in differentiating the subtle differences caused by different vegetative cover, different hydrologic characteristics, and a slightly different treatment.

Literature Cited

Bates, C. G., and A. J. Henry. 1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. U.S. Monthly Weather Review Supplement 30, 79 p.

Bosch, J. M., and J. D. Hewlitt. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55(1982)3-23.

Gary, Howard L. 1981. Patch clearcuts to manage snow in lodgepole pine. p. 335-346. *In* Proceedings of the 1980 Watershed Management Symposium, Volume I [Boise, Idaho, July 21-23, 1980] 597 p. Irrigation and Drainage Division, A.S.C.E. New York, N.Y.

Golding, Douglas L. 1981. Hydrologic relationships of interior Canadian watershed. p. 107-116. *In* Interior west watershed management. [Spokane, Wash., April 8-10, 1980] Cooperative Extension, Washington State University, Pullman.

Goodell, B. C. 1959. Management of forest stands in western United States to influence the flow of snowfed streams. *In* Symposium of Hannoversch-Munden, Volume I, Water and Woodlands, Publication 48. 340 p. International Association of Scientific Hydrology Gentbrugge.

Hibbert, A. R. 1967. Forest treatment effects on water yield. *In* Forest Hydrology. 813 p. W. E. Sopper and H. E. Lull, editors. Pergamon Press, N.Y.

Leaf, Charles Frank. 1969. Snowpack depletion and runoff in Colorado. Ph.D. dissertation, 154 p. Colorado State University, Fort Collins.

Leaf, Charles F. 1974. A model for predicting erosion and sediment yield from secondary forest road construction. USDA Forest Service Research Note RM-274, 4 p. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA Forest Service Research Paper RM-137, 31 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Leaf, Charles F., and G. E. Brink. 1973a. Computer simulation of snowmelt within a Colorado subalpine watershed. USDA Forest Service Research Paper RM-99, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Leaf, Charles F., and G. E. Brink. 1973b. Hydrologic simulation model of Colorado subalpine forest. USDA Research Paper RM-107, 23 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Retzer, J. L. 1962. Soil survey of Fraser alpine area, Colorado. Soil Survey Service 1956, No. 20, 47 p. USDA Forest Service and Soil Conservation Service. U.S. Government Printing Office, Washington, D.C.

Swanson, R. H., and G. R. Hillman. 1977. Predicting increased water yield after clearcutting verified in west-central Alberta. Information Report NOR-X-198, 40 p. Northern Forest Research Center, Edmonton, Alberta.

Troendle, Charles A., and Charles F. Leaf. 1980. Hydrology, Chapter III. *In* An approach to water resources evaluation of non-point silvicultural sources. EPA 60018-80-012, 173 pp. Environmental Research Laboratory. Athens, Georgia.

Troendle, Charles A., and Charles F. Leaf. 1981. Effects of timber harvest in the snow zone on volume and timing of water yield. p. 231-243. *In* Interior west watershed management. [Spokane, Wash., April 8-10, 1980] Cooperative Extension, Washington State University, Pullman.

Agriculture—CSU, Fort Collins

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Lubbock, Texas
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526